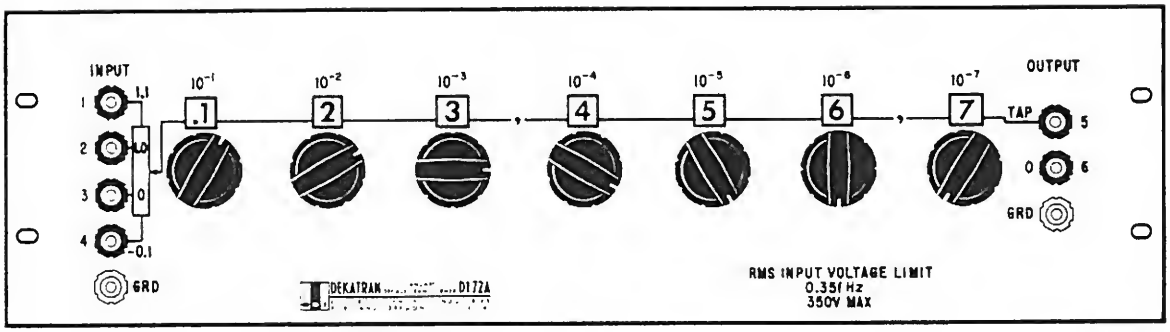
MODEL DT 72A

DECADE TRANSFORMER

Instruction Manual

Part Number 7203 September 1975



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SECTION I
INTRODUCTION

1.1 DESCRIPTION

The MODEL DT 72A DEKATRAN DECADE TRANSFORMER is a laboratory standard divider for establishing either voltage or current ratios at audio frequencies.

The DEKATRAN circuit is an auto-transformer with a variable tap. The tap position is indicated by the dial reading which gives the ratio of output turns to input turns. Additional windings extend the ratio above and below the input so that voltage ratios of -0.1 and +1.1 are available.

The accuracy of the DEKATRAN is established by intercomparisons over a wide range of frequencies and dial settings, traceable to a special NBS - certified transformer.

1.2 FEATURES

The inherent stability of the DEKATRAN assures permanent calibration over wide ranges of ambient temperatures, humidity, vibration, and shock. No special input voltage values are required for specified accuracy within the limits shown under "Maximum Voltage".

A 10% overwinding and a 10% underwinding on the first decade are brought out to terminals on the front panel. These terminals provide a convenient source for obtaining at 10:1 ratio for bridge type measurements. They are also a convenient source for driving a phase shifting network, especially when comparing values near the end of the scale.

The decade dials indicate the output voltage as a decimal part of the input. The output can be read to seven significant digits. The first dial has end stops to prevent accidental switching from zero to full output. Each of the other dials rotates continuously, with no end stops, minimizing setting time. Also, a 10% range overlap is provided on both ends of each decade except the first, reducing the number of individual dial adjustments necessary for null balance measurements.

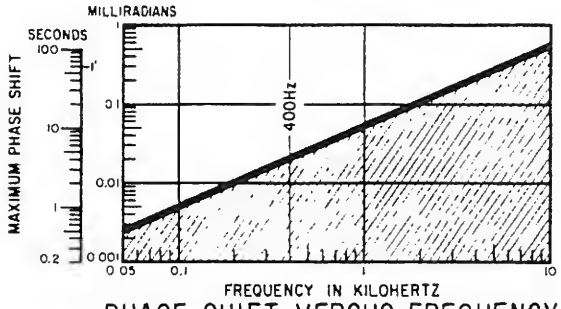
As dial settings are being changed, switching transients are minimized by a special circuit which couples the adjacent voltage steps through a resistor while the switching is taking place.

The high input impedance of the DEKATRAN divider makes it well suited for use in high impedance circuits without causing excessive loading.

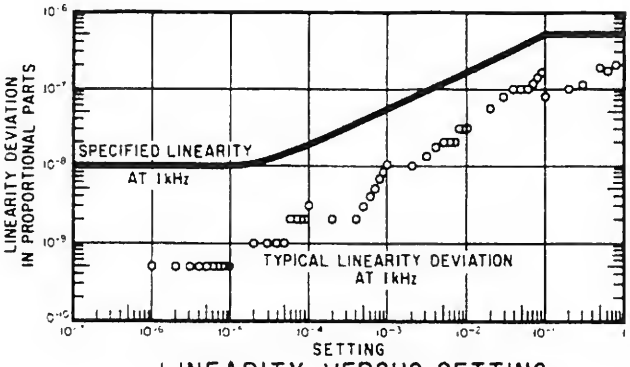
1.3 SPECIFICATIONS

LINEARITY AND PHASE SHIFT

The terminal linearity and phase shift of the DEKATRAN depend on the dial setting and the frequency. The specified values of these quantities for the MODEL DT 72A are shown in the curves below.



PHASE SHIFT VERSUS FREQUENCY

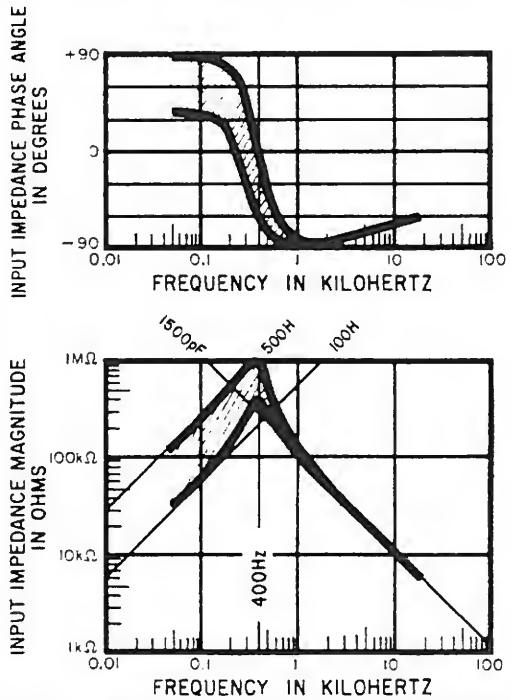


LINEARITY VERSUS SETTING

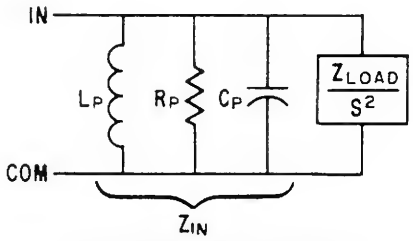
$$\text{LINEARITY DEVIATION} = \frac{\text{OUTPUT VOLTAGE}}{\text{INPUT VOLTAGE}} - \text{SETTING}$$

INPUT IMPEDANCE

With no output load the DEKATRAN has a high input impedance. This can be represented by the equivalent circuit shown below. A typical range of measured values for various dial settings and voltages is shown by the curves. When a load is connected to the output it is reflected to the input divided by the square of the DEKATRAN setting.



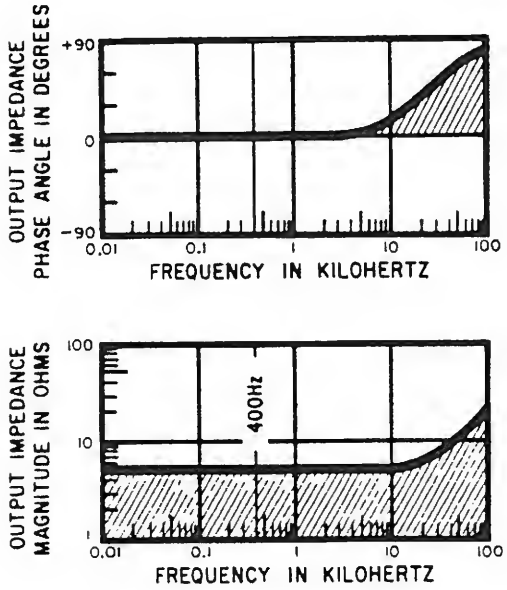
INPUT IMPEDANCE VERSUS FREQUENCY



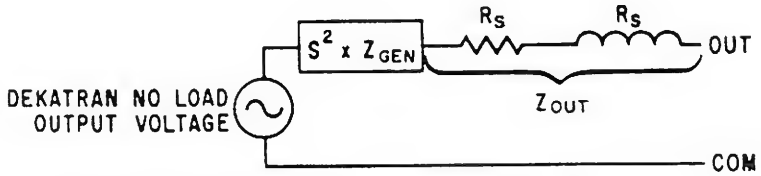
EQUIVALENT CIRCUIT FOR INPUT IMPEDANCE

OUTPUT IMPEDANCE

The DEKATRAN output impedance can be represented by the equivalent circuit shown below. Maximum values of the output impedance of the DEKATRAN alone are shown by the curves. In addition, any impedance in the source to which the unit is connected will be reflected to the output multiplied by the square of the DEKATRAN setting.



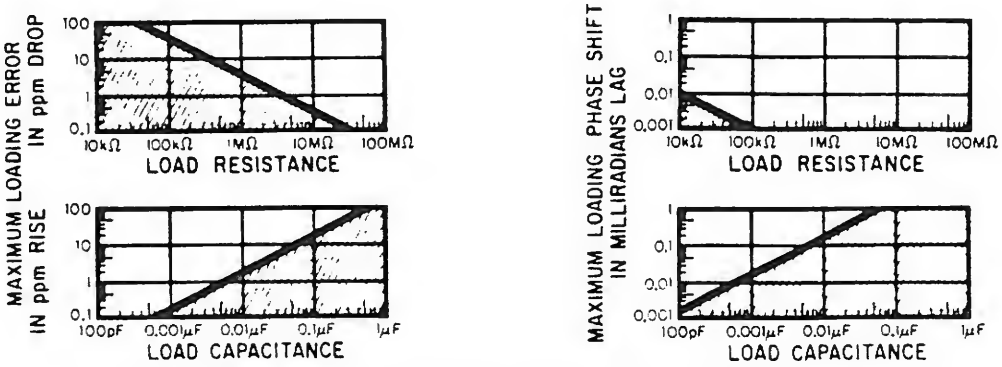
OUTPUT IMPEDANCE VERSUS FREQUENCY



EQUIVALENT CIRCUIT FOR OUTPUT IMPEDANCE

OUTPUT LOADING

When a load is connected to the output of the DEKATRAN the output accuracy and phase shift are affected. The resulting values will depend on dial setting, frequency, and the type of load. At a frequency of 400 Hz, typical maximum changes for resistive and capacitive loads are shown below.



EFFECTS OF LOAD RESISTANCE AND CAPACITANCE AT 400 Hz

Terminal Linearity (Initial and Long-Term) *

50 Hz to 1 kHz: ±0.5 ppm for settings 0.1 to 1.0;
$[0.5\ (10 \times \text{setting})^{1/2} + 0.01]$ ppm for settings 0 to 0.1.

Above 1 kHz: Multiply by f^2_{kHz}.

Below 50 Hz: Multiply by $50/f_{Hz}$.

Number of Decades: Seven.

Resolution: 0.1 ppm of input.

Range: -0.0111111 to +1.1111110.

Maximum Phase Shift:

Approximately 0.05 mrad/kHz for settings above 0.1.

Maximum Input Voltage: 0.35 V rms/Hz, 350 V max.

Maximum Input Current (DC):

For best performance no dc current should be permitted. DC input of 20 μA will decrease ac input voltage rating about 10% and increase distortion slightly; 200 μA will cause near saturation of core and serious errors.

Input Impedance:

Approximately 500 kΩ at 400 Hz. Typical range of measured values for various dial settings, frequencies, and voltages shown in curves.

Input Inductance: Approximately 100 to 400 H depending on excitation.

Output Current: 1 A max.

Output Impedance: Approximately 5Ω max in series with 30 μH.

Calibration Date:

Certified test report supplied with unit gives calibration data for each step of the first three decades to better than ±0.2 ppm.

Dimensions:

Width 19 in. (48.25 cm), Height 5.25 in. (13.3 cm), Depth 7.1 in. (18 cm).

Weight: 18 lb (8.2 kg).

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* All setting combinations producing the same nominal output voltage remain within the stated linearity specifications.

SECTION II

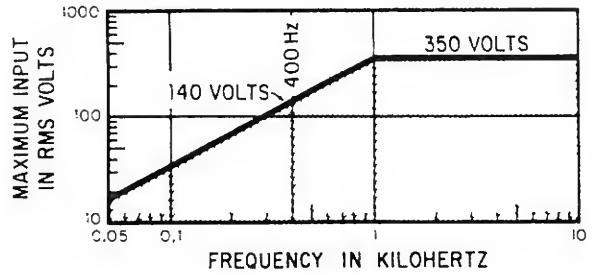
OPERATION

The DEKATRAN transformer is generally used in one of the following applications: to calibrate voltmeters, to calibrate ammeters, to calibrate voltage dividers, for transformer ratio measurements, or for impedance comparison measurements. The instructions in this section provide the basic information necessary to perform these measurements. If more information is desired, consult the THEORY section.

More detailed information about specific application of the Model DT 72A Decade Transformer may be found in ESI technical publications TA-8 and EB-29. These articles may be obtained by using the order form at the back of this manual. A complete discussion of the methods for making bridge-type measurements with a decade transformer is given in an article by D. L. Hillhouse and H. W. Kline, titled, "A Ratio Transformer Bridge for Standardization of Inductors and Capacitors". This article was published in the 1960 volume of IRE Transations on Instrumentation, page 251.

CAUTION

In all applications the maximum output current at any terminal should not exceed 1 ampere, and the voltage should be limited as shown in the following graph:



MAXIMUM INPUT VOLTAGE VERSUS FREQUENCY

2.1 VOLTMETER CALIBRATION

The circuit diagram and interconnection wiring diagram for voltmeter calibration are shown in Figure 2.1a. The isolation transformer is used to prevent power line coupling between the generator and the voltmeter. V_1 may be either the calibrated or uncalibrated voltmeter. The equation relating the two voltmeter readings is:

$$V_2 = (V_1)(\text{dial setting})$$

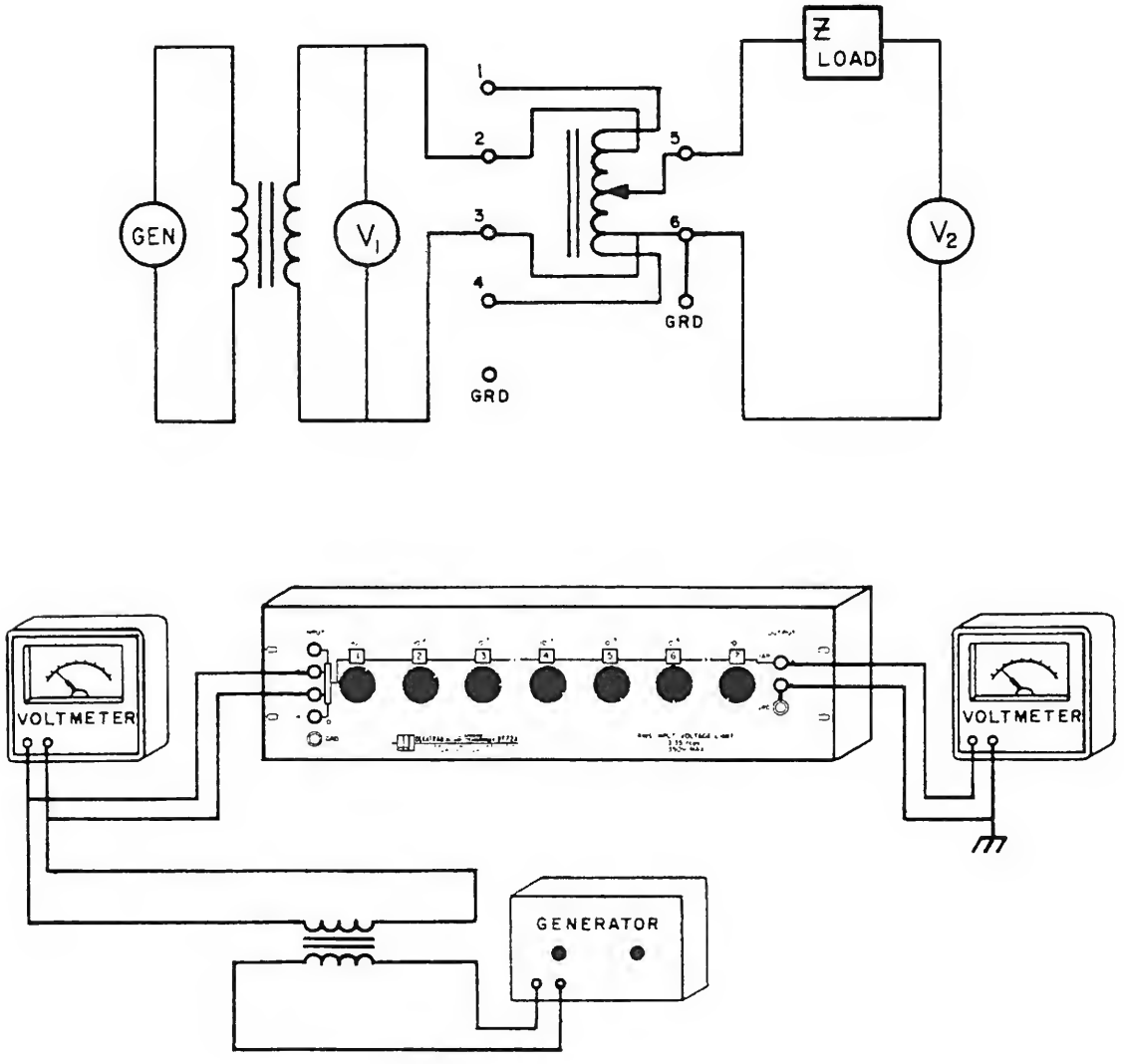


FIG. 2.1a

The only requirement of the circuit is that load impedance (impedance of the voltmeter) be of a sufficient magnitude, so as not to load the transformer. Whether or not the load impedance can be neglected depends on the degree of accuracy desired. The graph in Figure 2.1b gives the maximum load resistance error in ppm drop for load resistances from 10k to 100 meg.

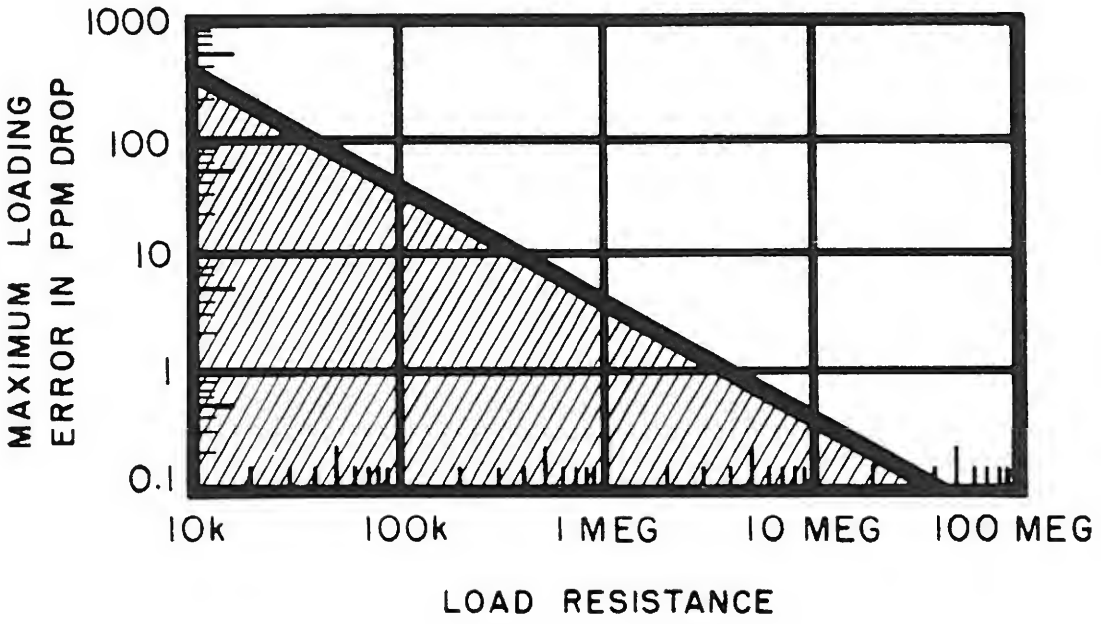


FIG. 2.1b

(continued next page)

If the loading error is excessive then the load current must be isolated from the decade transformer. This is accomplished by using a second divider as shown in Figure 2.1c to carry the current. This second divider does not have to be calibrated. The desired ratio is then set on the calibrated divider dials and the uncalibrated divider is adjusted for a null reading on the detector. The equation relating the two voltmeter readings is:

$$V_2 = (V_1)(\text{dial setting})$$

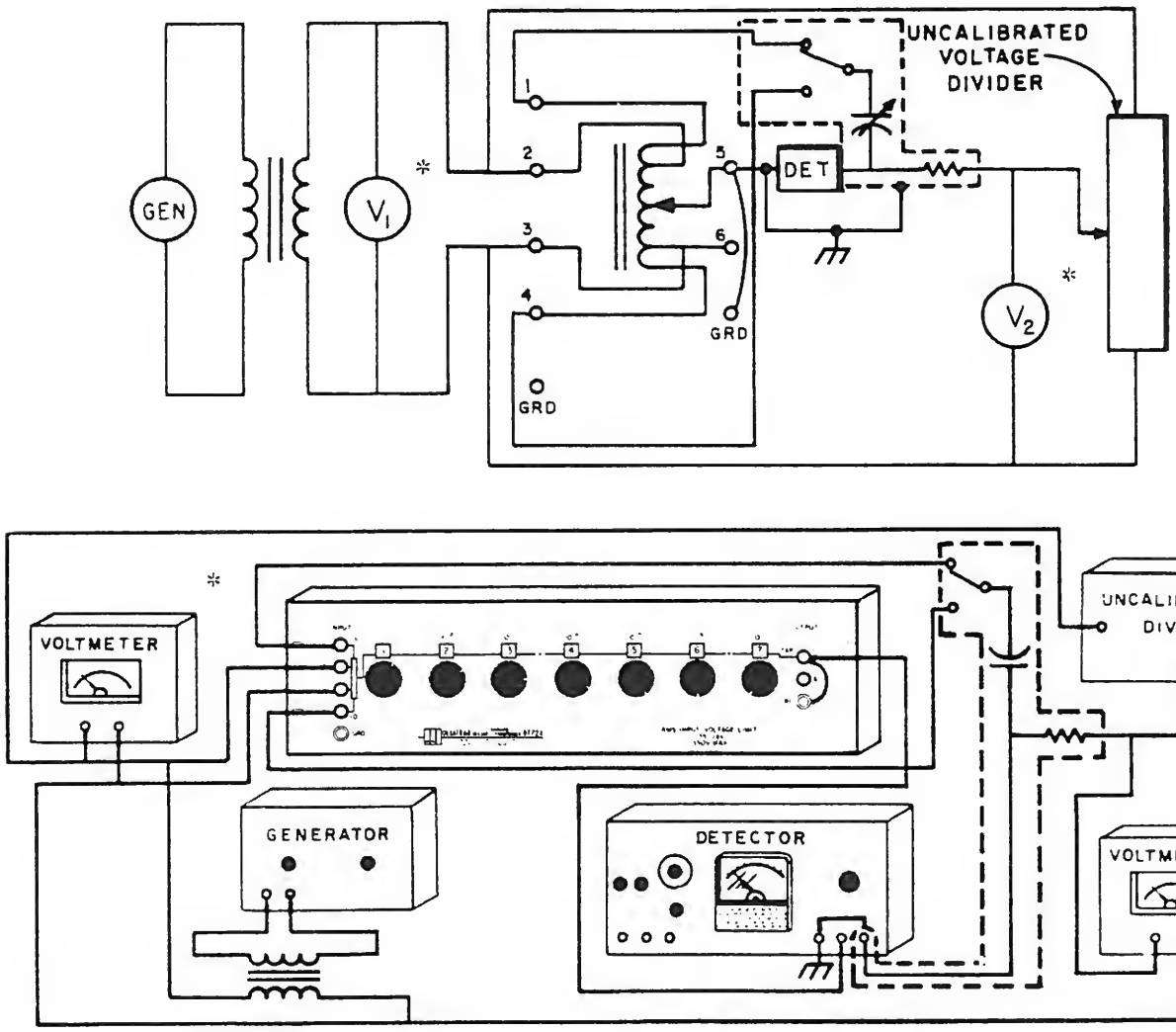


FIG. 2.1c

Phase compensation may be necessary to reach a null balance, particularly at higher frequencies. The switchable capacitor in Figure 2.1c shows the most common method of phase compensation for this circuit. Typical values for the resistor-capacitor combination are 3 kilohms and 0-1000pf.

*If voltmeters are grounded, detector must be isolated from ground.

2.2 AMMETER CALIBRATION

When the Model DT72A is used as a current divider, a current generator and ammeter are connected to the OUTPUT terminals, 5 and 6. The circuit diagram and interconnection wiring diagram for ammeter calibration are shown in Figure 2.2a. The equation relating the two ammeter readings is:

$$A_2 = (A_1)\,(\text{dial setting})$$

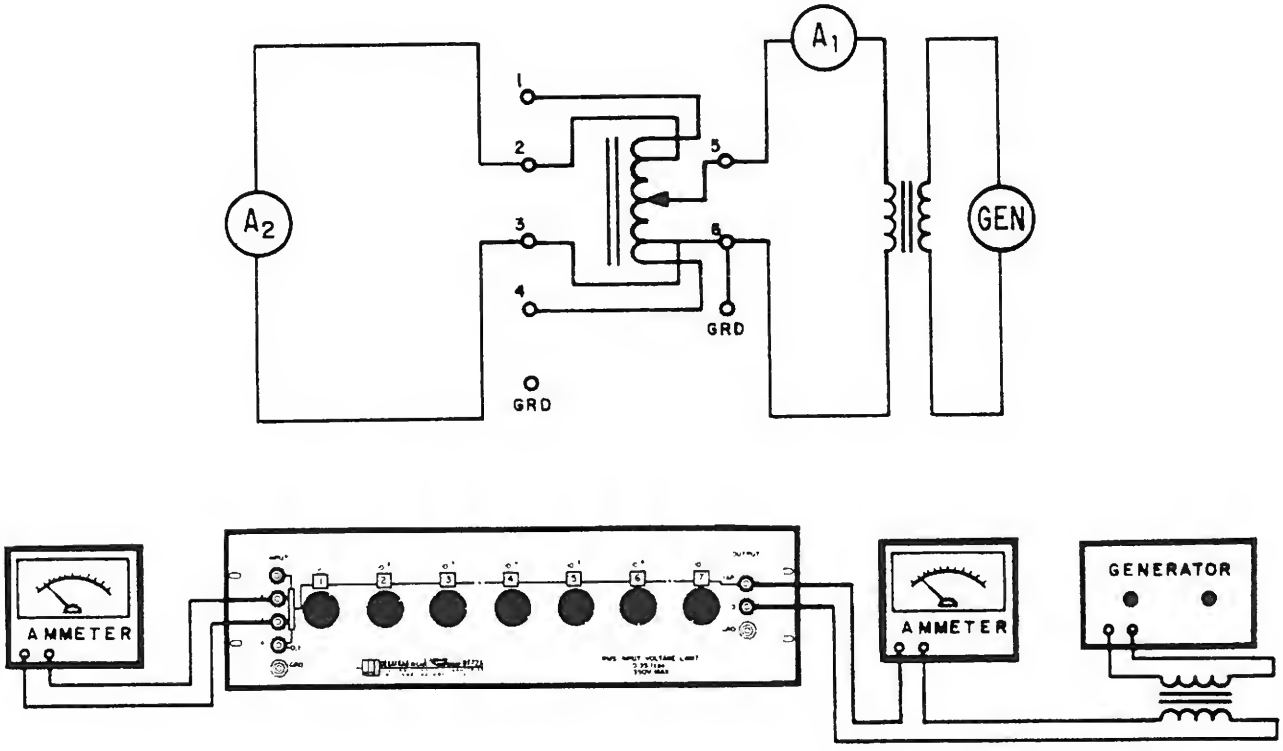


FIG. 2.2a

In current divider applications a negligible voltage should appear across the input impedance of the DEKATRAN. The graph in Figure 2.2b gives the error due to the impedance of the ammeter for ammeter resistances from 10 milliohms to 100 ohms.

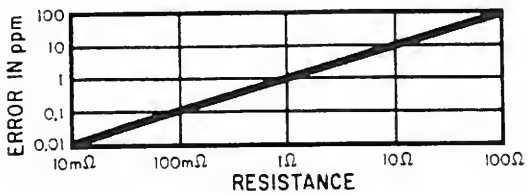


FIG. 2.2b

If the error is excessive then the load voltage drop must be separated from the voltage drop across the transformer. This is done by using a second divider as shown in Figure 2.2c. This second divider does not have to be calibrated. It balances out the voltage drop across the calibrated transformer.

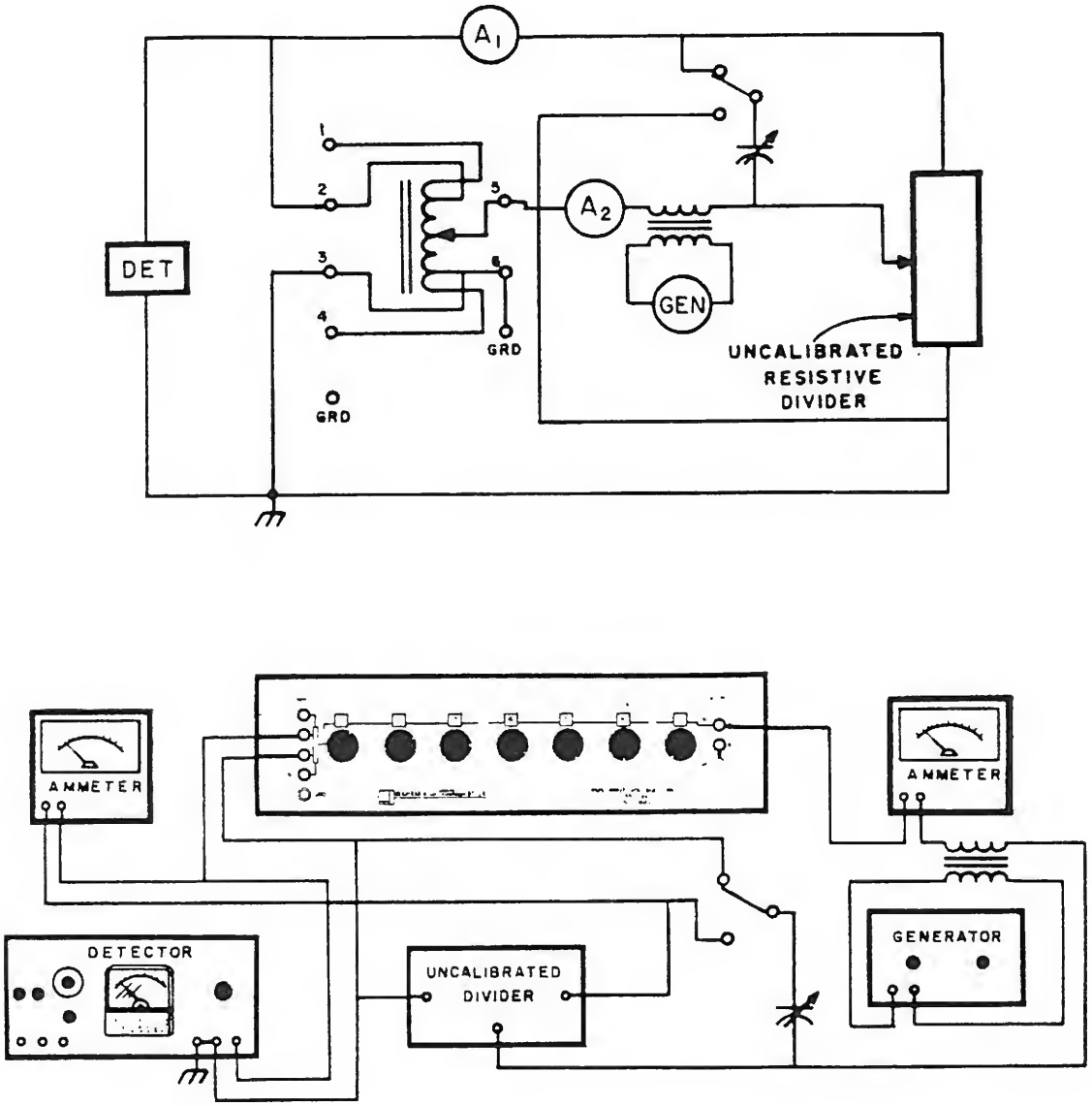


FIG. 2.2c

The desired ratio is set on the dials of the DT 72A and the uncalibrated divider is adjusted for a null reading on the detector. The switchable capacitor (typically 0-1000pf) is for phase compensation and may be needed to obtain a null balance, particularly at higher frequencies. When a null balance is reached the equation relating the two ammeter readings is:

$$A_1 = (A_2)(\text{dial setting})$$

2.3 VOLTAGE DIVIDER CALIBRATION

A decade transformer is frequently used to calibrate another decade transformer or for ac calibration of a resistive decade divider as shown in Figures 2.3a and 2.3b.

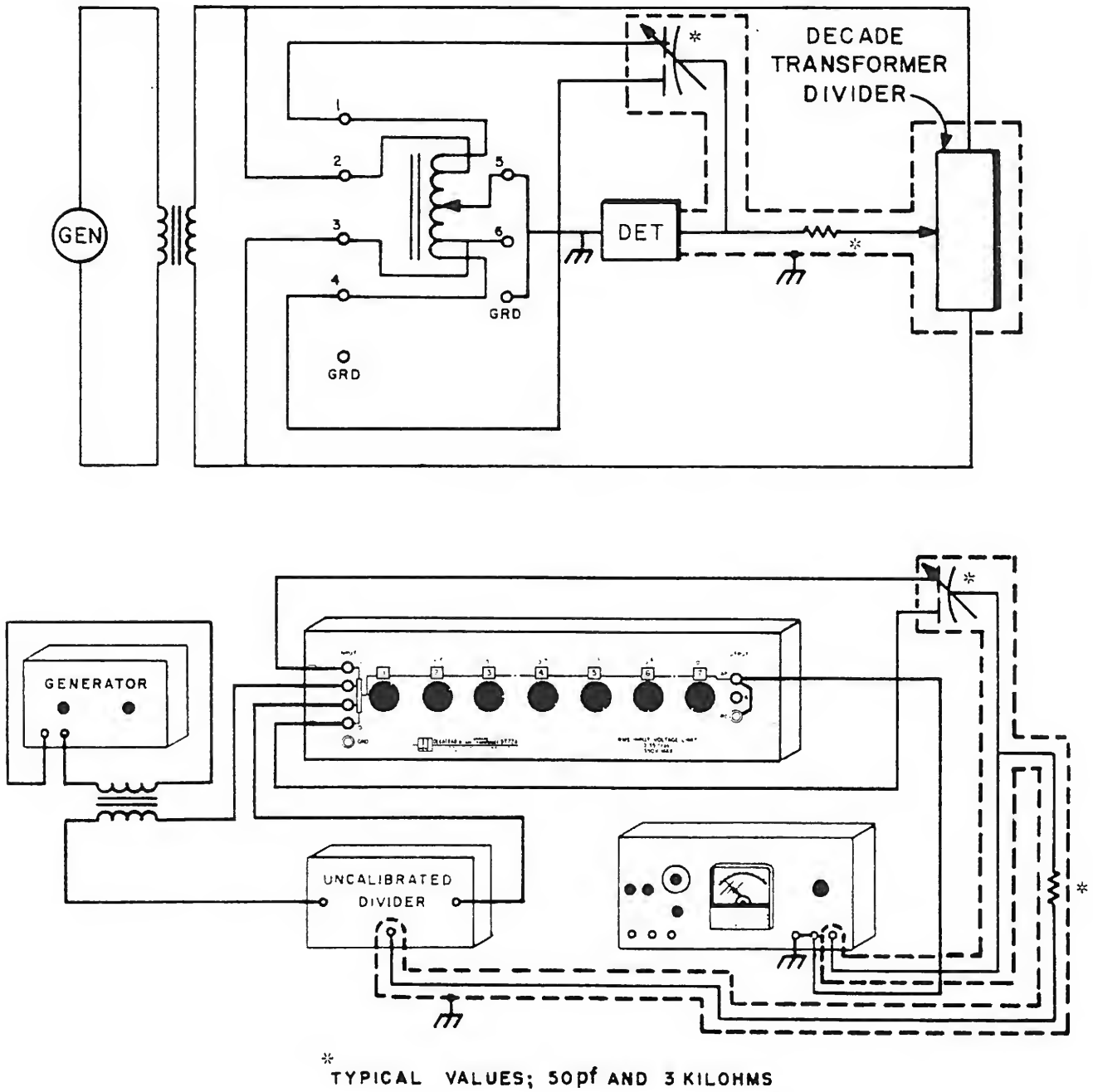


FIG. 2.3a

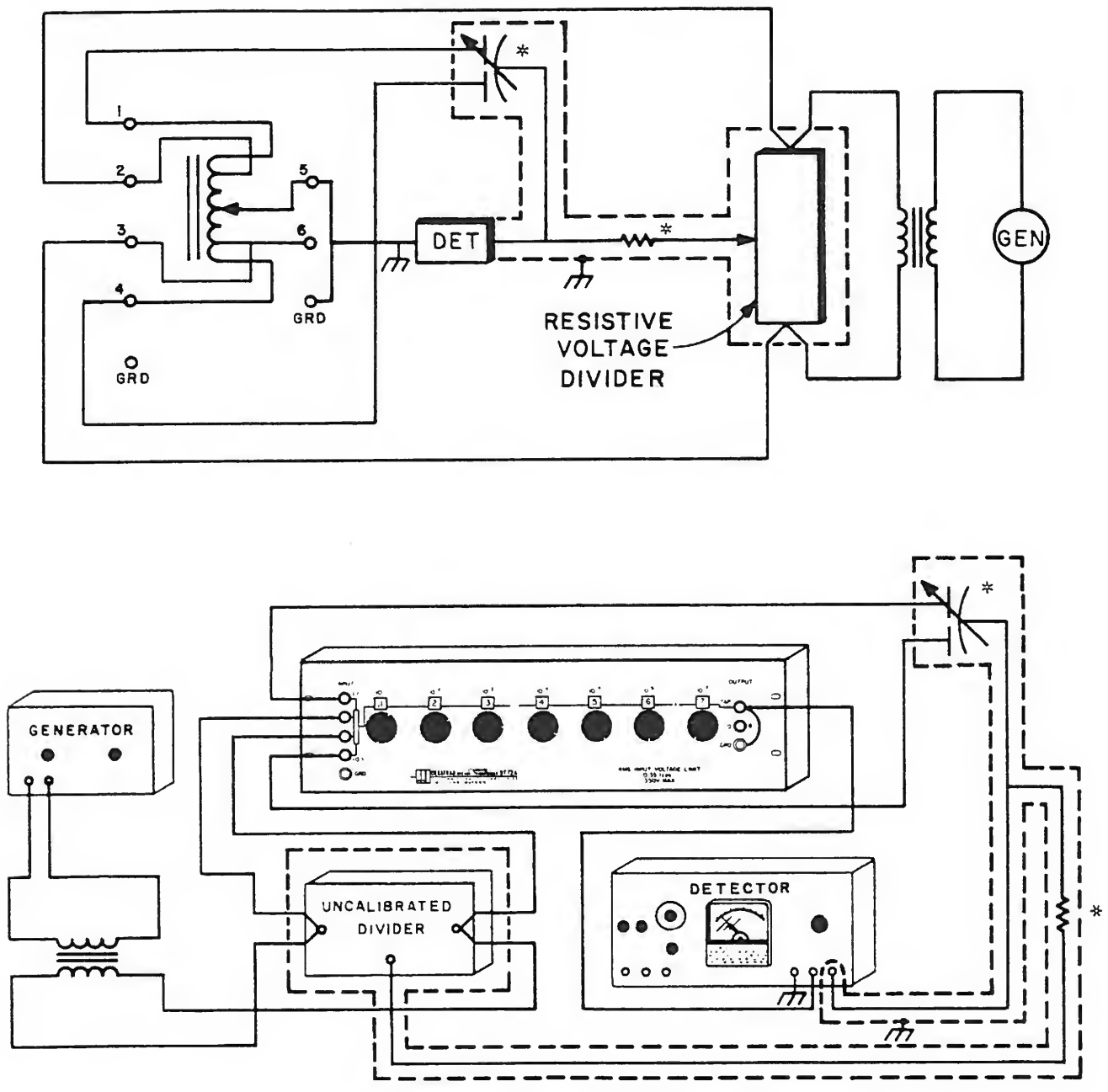

1
2
3
4
5
6
GRD
GRD
DET
*
*
RESISTIVE
VOLTAGE
DIVIDER
GEN
GENERATOR
UNCALIBRATED
DIVIDER
DETECTOR
*
* TYPICAL VALUES: 50pf AND 3 KILOHMS

FIG. 2.3b

In the circuit shown in Figure 2.3a a differential capacitor is used to adjust for any phase difference between the two dividers. Resistance is added in series with the tap of the divider being calibrated, as shown, so that its output resistance will be much larger than its reactance. The differential capacitor is connected from the detector end of the resistor to the overwindings of the DT 72A. This capacitance is used to draw a small amount of current through the resistor which in turn causes a small quadrature voltage drop across the resistor. If this voltage is extremely small in comparison to the total voltage across the dividers, it can be considered as being quite accurately in quadrature and will have a negligible effect on the magnitude calibration.

If a large difference in phase is to be corrected, care must be taken to see that the current through the resistance is exactly at right angles to the applied voltage. Any phase difference from 90° in the current through the resistor will cause a voltage drop in phase with the transformer voltage being calibrated, and will affect the magnitude ratio measurement.

The circuit used for the calibration of resistive dividers, shown in Figure 2.3b, is very similar to the transformer divider calibration circuit. However, in the case of the resistive divider the resistance is added in series with the tap of the divider to provide an output resistance when the divider tap is near its end points.

Usually, very sensitive detectors must be operated with one of their two terminals grounded to prevent stray pickup at their input terminals. In Figures 2.3a and 2.3b the grounded side of the detector is connected to the tap of the DT 72A. This places stray capacitance to ground either across the detector or across the low impedance transformer arms.

If the DT 72A dial settings at the end point null adjustments differs from 0.000,000,0 and 1.000,000,0 it will sometimes be necessary to make a correction for all dial settings. This can be most easily accomplished by a simple linear interpolation. By plotting the end point errors on a graph and connecting these two points with a line as shown below, the error at any dial setting may be determined by inspecting the graph. An example is given in Figure 2.3c.

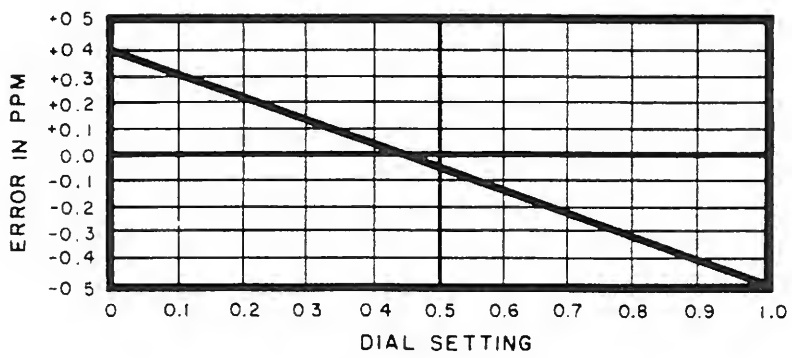


FIG. 2.3c

2.4 TRANSFORMER RATIO CALIBRATION

The circuit used for step-down transformer calibration, shown in Figure 2.4a, is essentially the same circuit as that used for the calibration of a decade divider. The calibration procedure is discussed in Section 2.3.

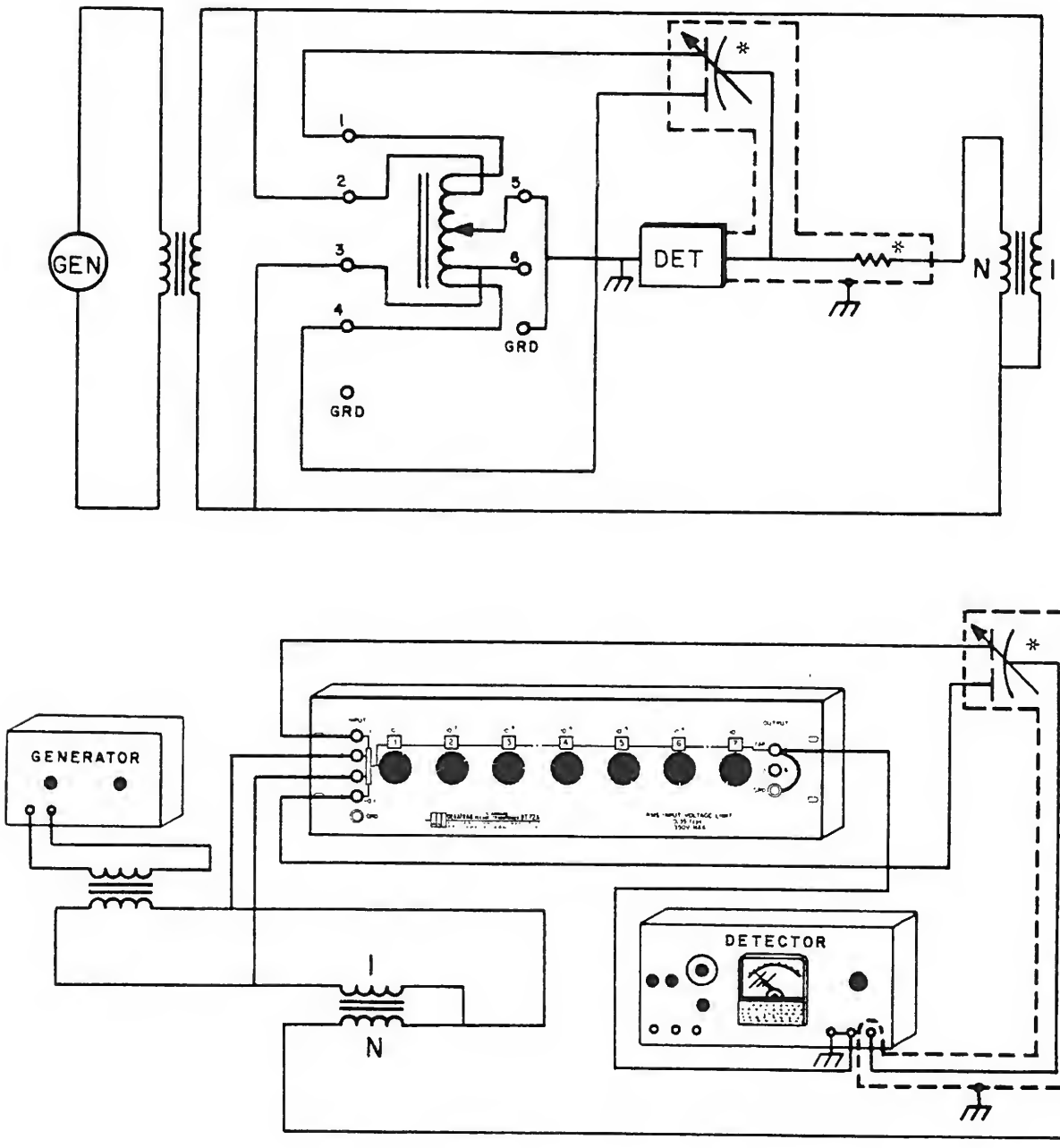


FIG. 2.4a

When calibrating a step-up transformer the first circuit cannot be used since the DT 72A would have to be operated at a ratio equal to or greater than 1.0.

A circuit which is suitable for the calibration of step-up transformers with ratios of 10:1 or less is shown in Figure 2.4b. The equivalent series impedance of the -0.1 overwinding of the DT 72A is approximately 0.5 ohm. Consequently, if the load due to the impedance of the transformer being calibrated is 500k or more, the error due to loading will be less than 1 ppm. Load impedances which are less than 500k may cause some significant error and therefore this error should be calculated or determined empirically by adding an equivalent load in parallel with the transformer being calibrated and noting the resulting equivalent error. The balance equation for this circuit is:

$N = 10 (S + .1) = 10S + 1$ where S = dial setting of DT 72A

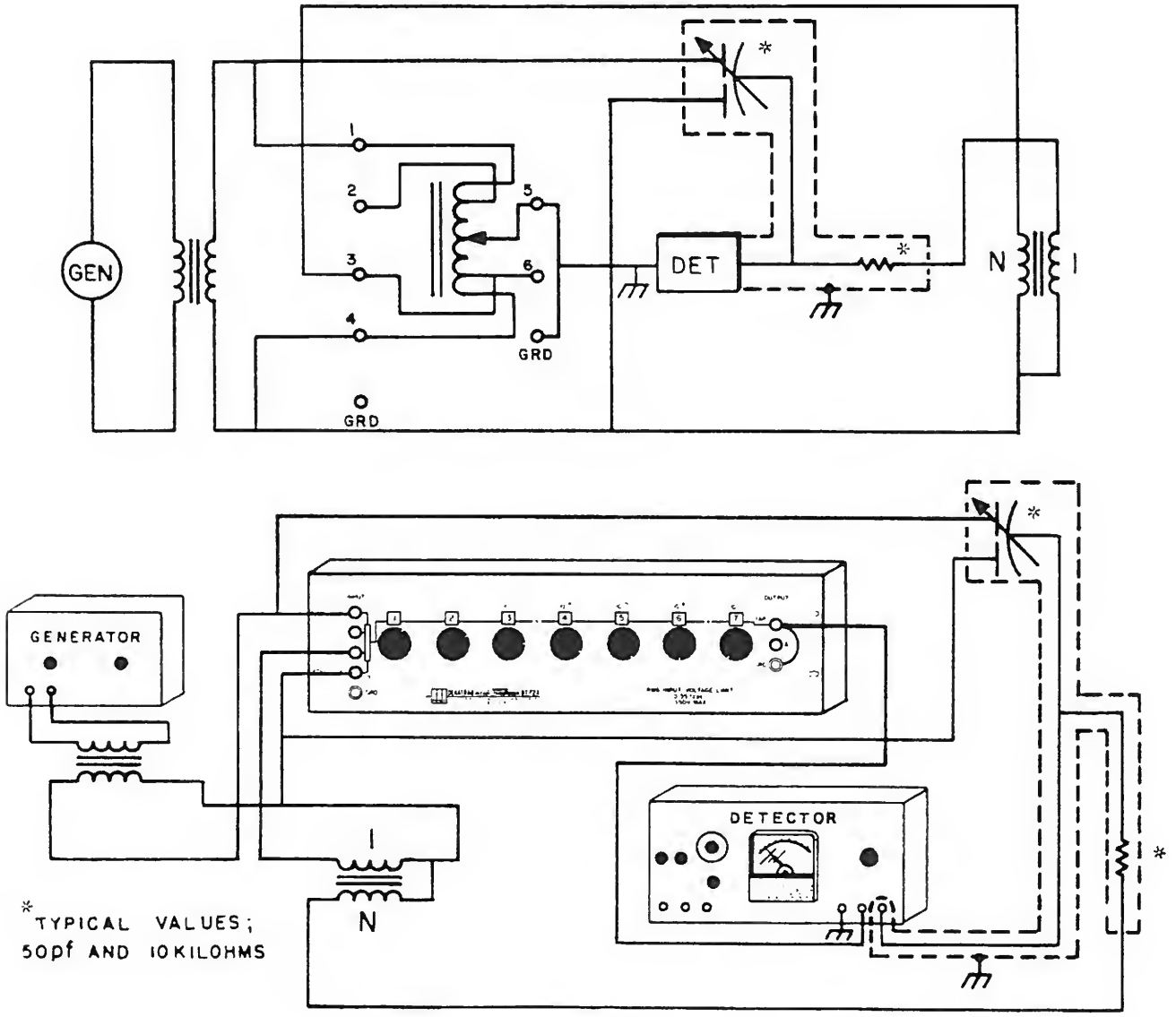


FIG. 2.4b

2.5 IMPEDANCE COMPARISON MEASUREMENTS

The DT 72A can be used to read the voltage ratio of two similar impedances as shown in Figure 2.5a.

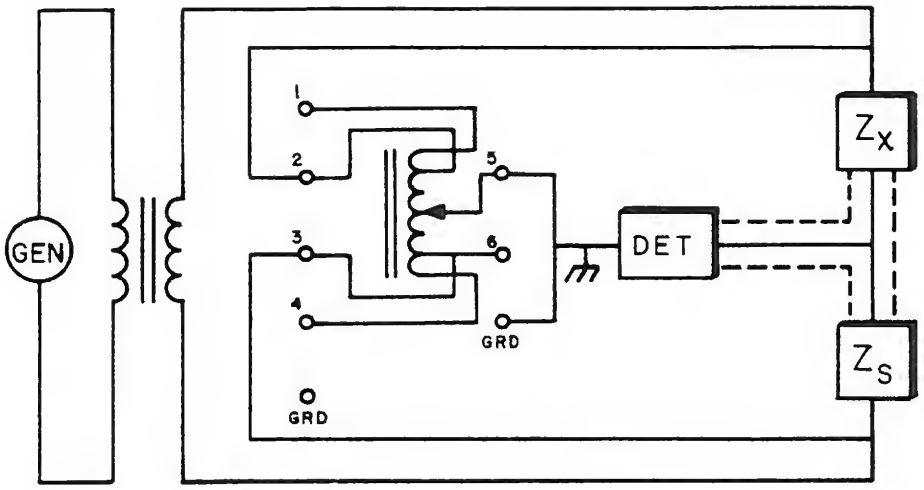


FIG. 2.5a

The voltage across the two series connected impedances are in the same ratio as the impedances. Therefore, a DT 72A can be used to compare a known impedance with an unknown impedance, the unknown impedance being equal to:

$$Z_x = \frac{(1 - S)}{S} Z_s = (\frac{1}{S} - 1) Z_s$$

Where Z_s is the known impedance and S is the setting of the DT 72A at balance.

The phase balance of impedance bridges may be provided as a part of the unknown or standard impedance or as a quadrature voltage added in series with one of the taps of the DT 72A. If the phase balance is accomplished by an element (Z_p) in series with the impedance, care must be taken to keep the

capacitance from the junction to ground to a minimum, maximizing Z_L (see Figure 2.5b).

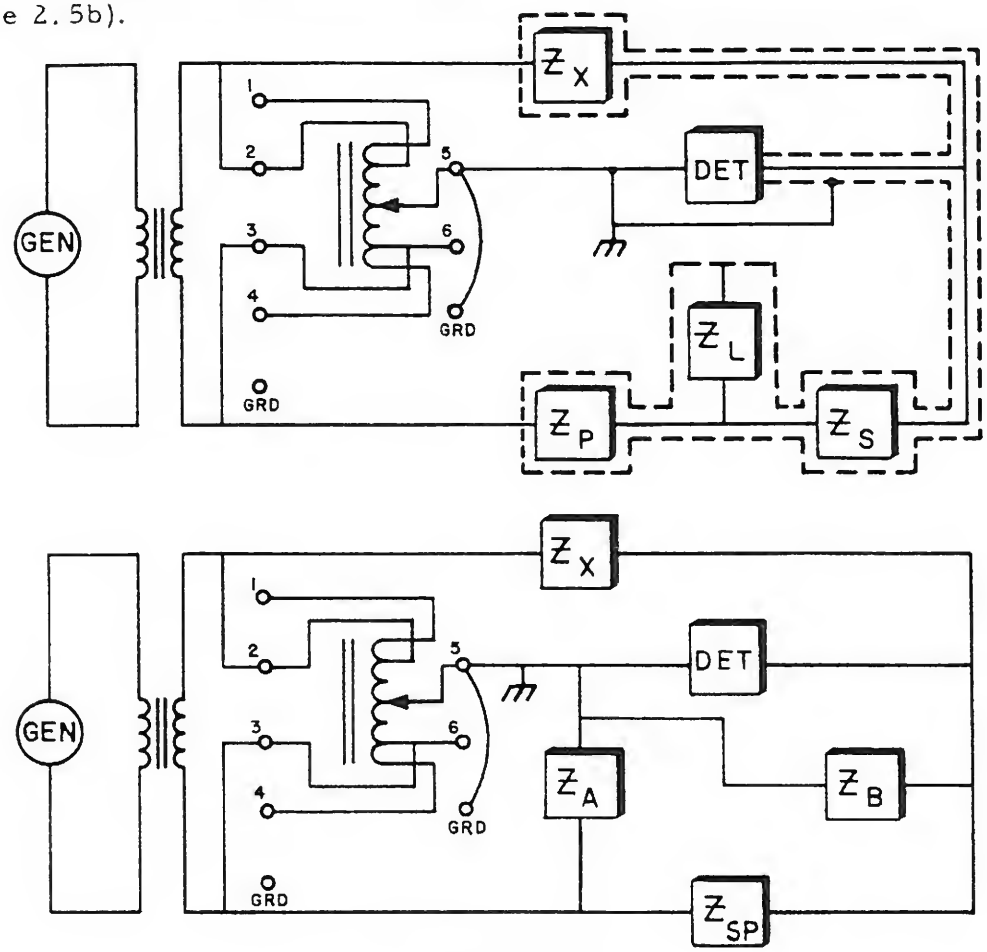


FIG. 2.5b

By means of a wye to delta transformation it can be seen that the only impedance of interest is Z_{sp}. Since Z_b is across the detector it will not affect the measurement accuracy. Z_A is across a low impedance transformer arm and can be neglected for all reasonable leakage impedances. From the transformation we get

$$Z_{sp} = Z_s + Z_p + \frac{Z_s Z_p}{Z_L}$$

where $\frac{Z_s Z_p}{Z_L}$ is the error term introduced by Z_L.

Additional information on this topic is given in the two papers, "A Ratio Transformer Bridge for Standardization of Inductors and Capacitors" and "Calibration of a Decade Transformer Having One ppm Linearity" at the end of this manual.

The calculations for the unknown impedance using the circuit shown in Figure 2.5a are somewhat laborious since the inverse of the DT 72A setting must be calculated. By utilizing the overwinding on the DT 72A as shown in Figure 2.5c with high unknown impedances, the impedance ratio calculation is reduced to a simple decimal point shift.

$$Z_x = 10\ (S)\ Z_s$$

where S is the DT 72A dial reading.

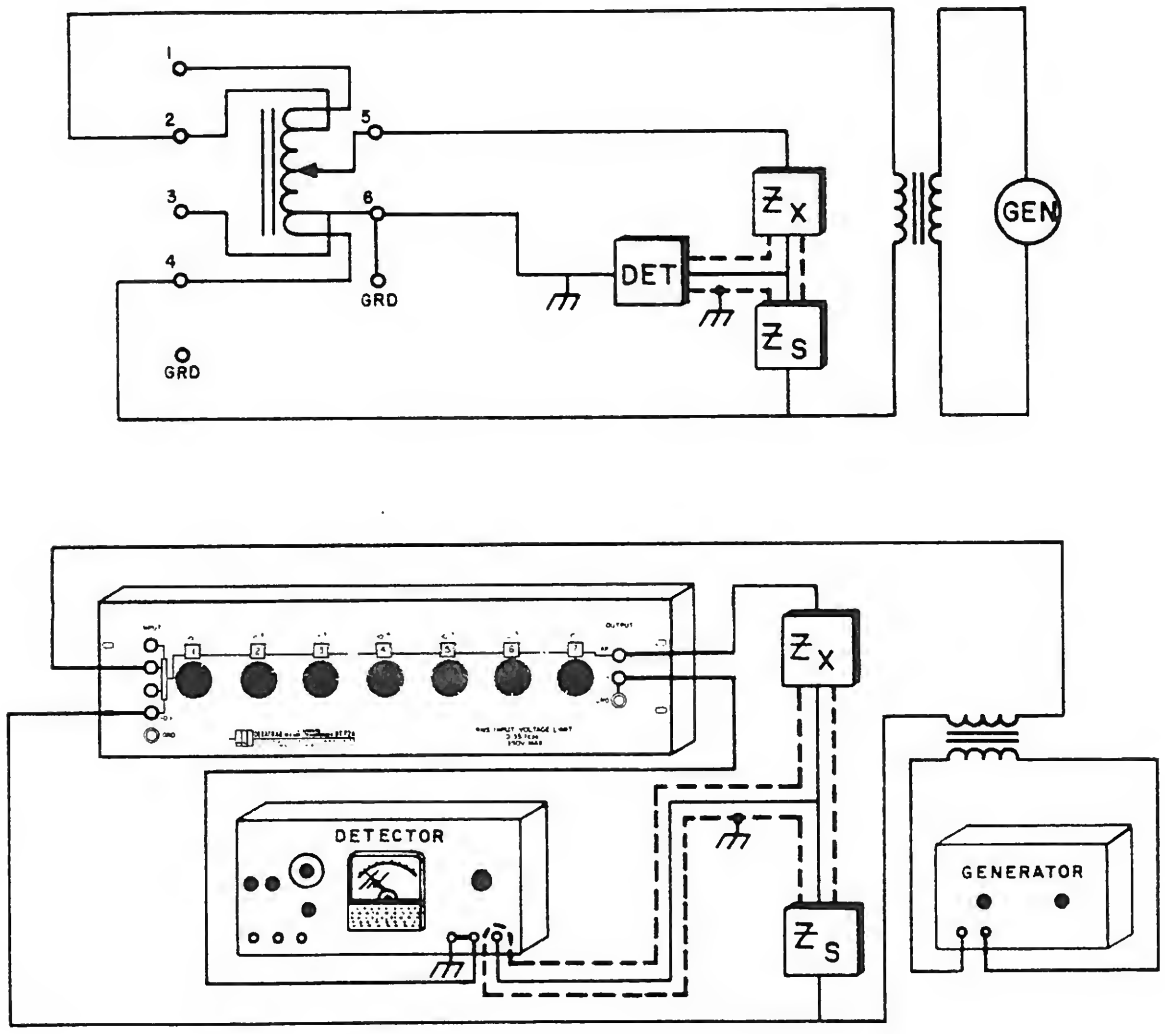


FIG. 2.5c

A second alternative method which is suited for 10:1 ratio, low impedance comparisons is shown in Figure 2.5d. In this circuit the power to the unknown and standard impedances is supplied directly from the generator and will not load the transformer. At low settings on the DT 72A, the unused upper winding will cause loading, resulting in errors. Therefore, the decade transformer should be operated between settings of 0.9 and 1.1 for highest accuracy. The impedance ratio equation is

$$Z_x = 10(S)\ Z_s$$

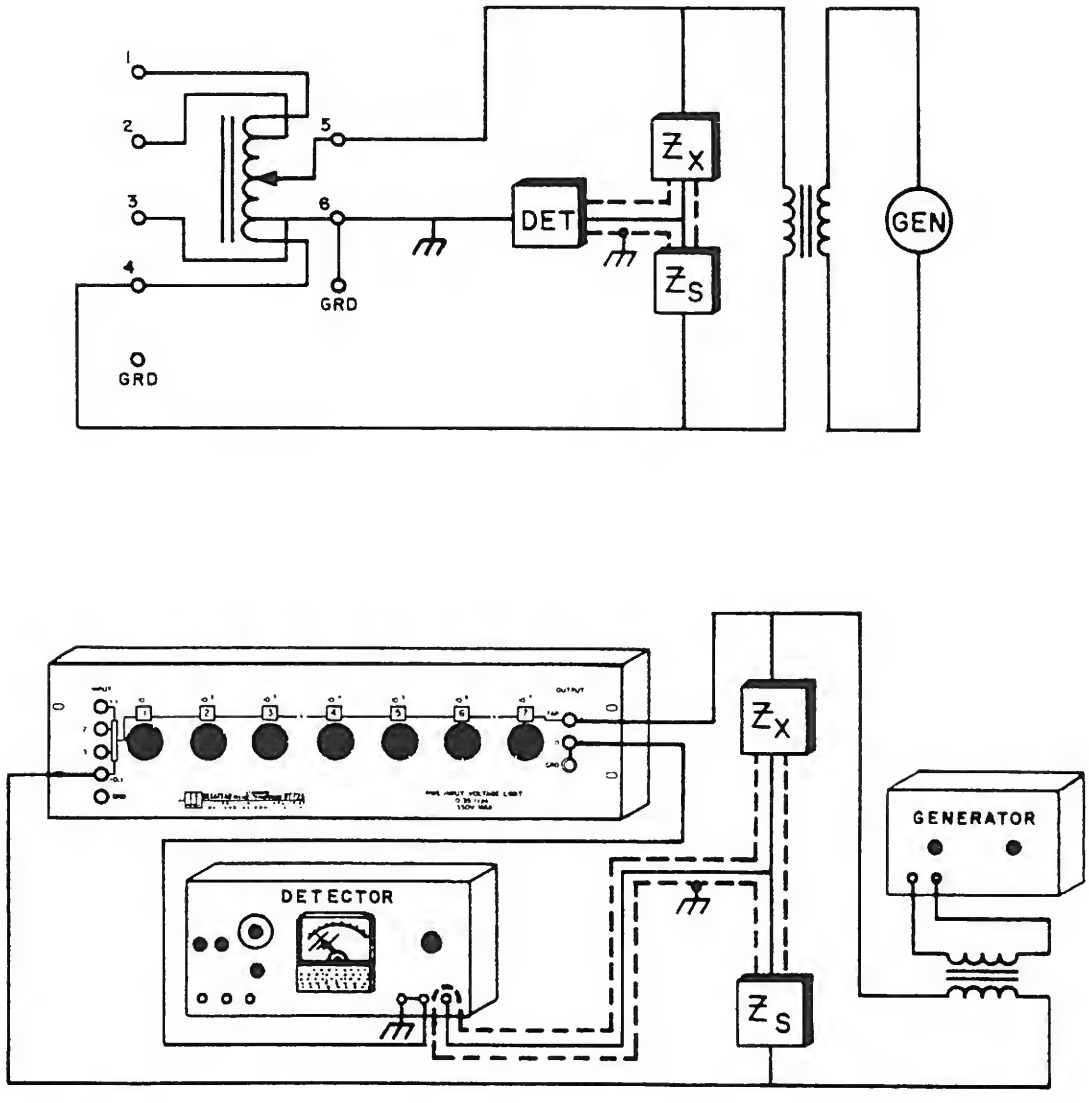


FIG. 2.5d

2.5.1 CAPACITANCE COMPARISONS

The circuits outlined thus far have only explained the basic principles of impedance comparisons. This section will discuss the details of devising circuits to make accurate capacitance measurements.

THREE TERMINAL CAPACITORS

Figure 2.5e shows the connections for the measurement of a three-terminal capacitor. With this circuit one of the stray capacitances is across the detector where it will affect only the sensitivity. The other stray is across a low impedance transformer winding which will not be noticably affected by the loading of reasonable values of stray capacitance. The two capacitors being compared are brought into angle balance by a "D" control in the standard capacitor arm.

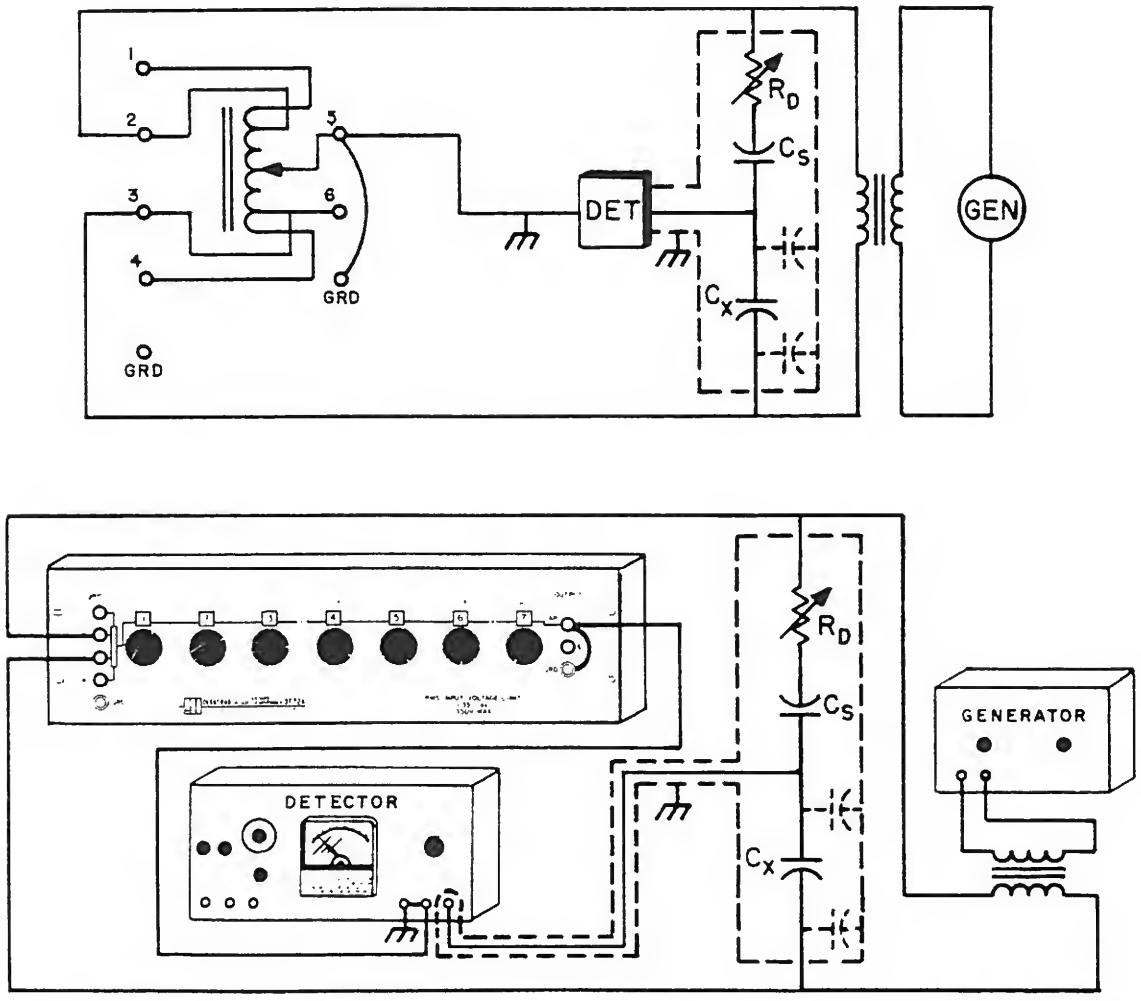
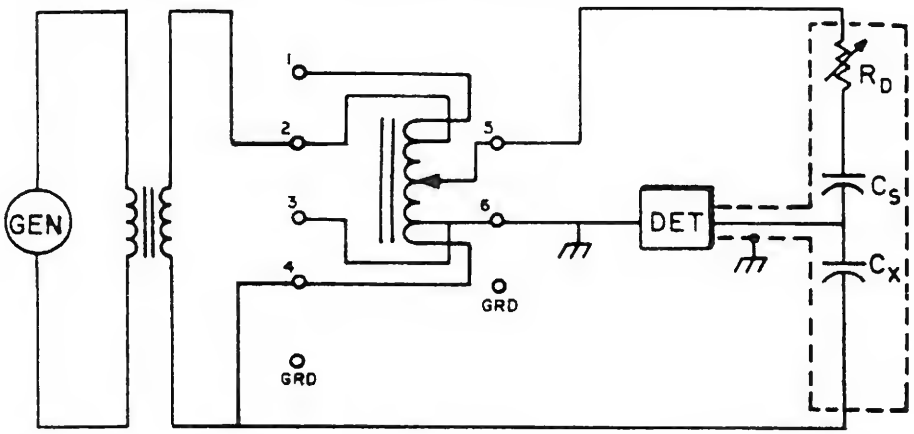


FIG. 2.5e

LOW VALUE CAPACITORS

When measuring a low value capacitor the circuit in Figure 2.5f should be used. Current is supplied to the capacitors from the transformer. With sufficiently high impedance capacitors the loading error can be neglected.

$C_x = 10\ (S)\ C_s$ where S is the DT 72A dial setting



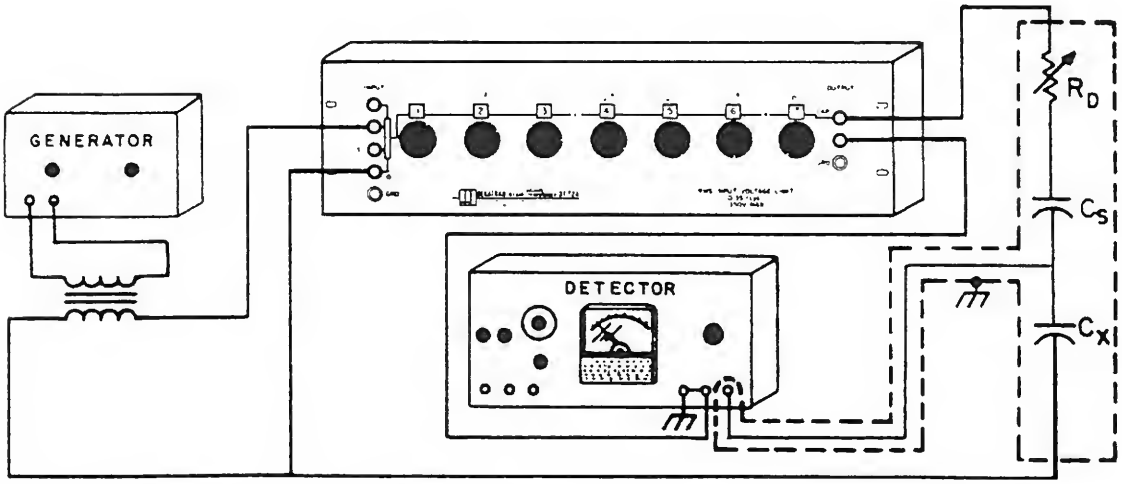


FIG. 2.5f

HIGH VALUE CAPACITORS

When high value capacitors are to be measured, the current can be supplied directly to the capacitance string and the transformer can be fed as shown in Figure 2.5g. This circuit permits a four-terminal measurement of the unknown capacitor to avoid lead and contact resistance and inductance errors. The transformer can be operated at a very low setting for obtaining a high ratio between the unknown and standard capacitors. However, transformer errors will increase for lower settings of the transformer dials.

$C_x = 10\ (S)\ C_s$ where S is the DT 72A dial setting

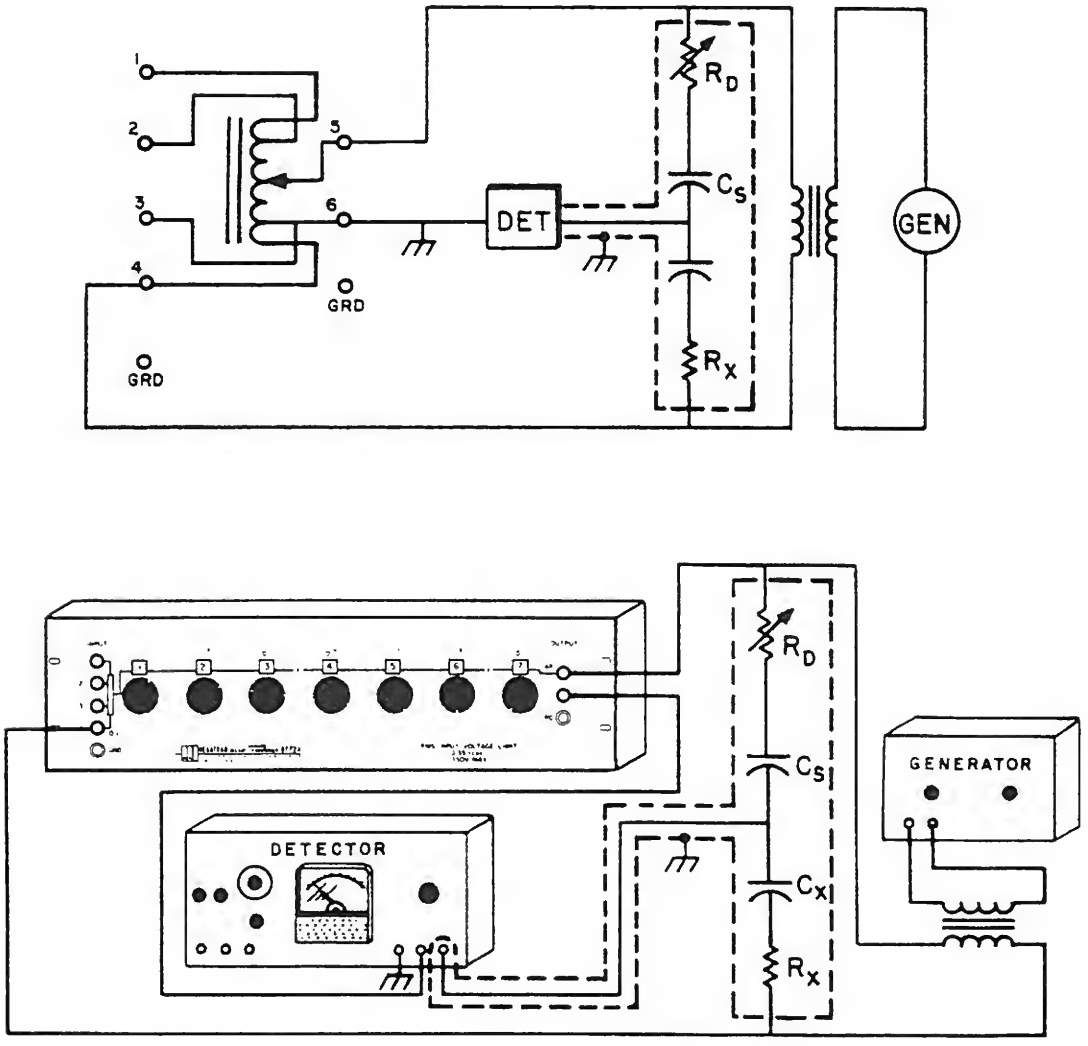


FIG. 2.5g

SECTION III

THEORY

Current flowing through a loop of wire creates a magnetic field. The change of flux inside a loop of wire creates a voltage. If a sine wave of voltage is applied to a zero resistance loop of wire, enough current will be drawn to create a flux which will change rapidly enough to generate a voltage in the loop equal to the applied voltage. If some of this flux goes through another loop of zero resistance wire nearby, a voltage somewhat less than the applied voltage will be generated. If a core of high permeability iron goes through the two loops of wire, most of the flux generated by the charging current will be confined to the iron core and will therefore go through both coils. As a result, the generated voltages in both coils will be exactly equal.

The accuracy of a transformer voltage divider is determined primarily by the permeability of the core material used in its construction. The accuracy can be improved by the use of proper winding techniques.

3.1 SOURCES OF ERROR

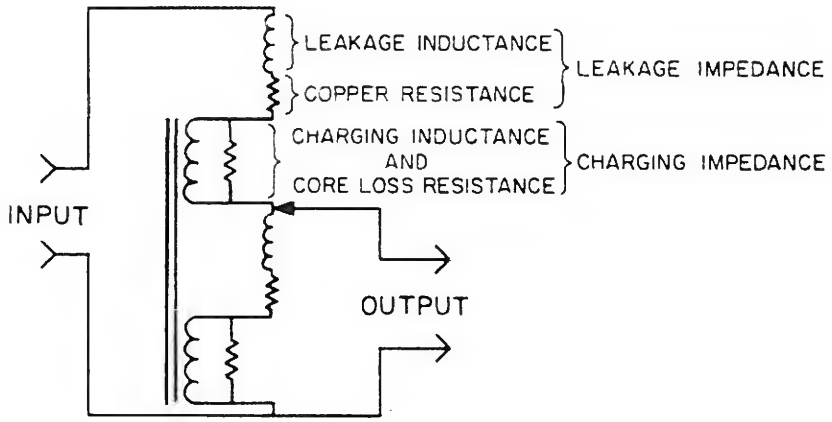


FIG. 3.1a

The equivalent circuit of a transformer shown in Figure 3.1a will have a leakage inductance which represents the flux which is generated by part of the winding but does not go through the other part of the winding, a series copper resistance, a primary inductance which results from the generation of the flux which threads through all of the windings, and a core loss resistance. The voltage which is generated by the charging inductance will be divided

exactly as the turns ratio, but the voltage across the leakage inductance and resistance will not be so perfectly divided because the leakage inductance and winding resistance will be different in different parts of the winding. The total voltage drop between taps is the sum of the transformer generated voltage and the voltage drop across the leakage inductance and resistance produced by the current flowing into the transformer. If the transformer secondary is open circuited, this current is determined by the charging inductance and core loss resistance. The voltages across the leakage and charging impedances will be directly proportional to these impedances, so the total voltage across the leakage impedance will be to the total input voltage as the leakage impedance is to the charging impedance.

LEAKAGE INDUCTANCE

Most of the flux in an air core transformer does not cut the other windings of the transformer so the leakage inductance of a transformer is approximately equal to the inductance of a winding of the same configuration on an air core. When this air core is replaced by iron the inductance will increase by a factor approximately equal to the permeance of the iron circuit relative to the permeance of the air that is replaced. This ratio is approximately equal to the permeability of the iron. Thus, if the iron has a permeability of one hundred thousand, we can expect the voltage across our leakage inductance to be about one one hundred thousandth of the input voltage. The current drawn by the core loss resistance will produce a quadrature voltage in the leakage inductance.

COPPER RESISTANCE

The transformer winding has resistance. The current through this winding resistance will produce additional voltage drops. The in-phase voltage will be about equal to the input voltage times the ratio of the copper resistance to the core loss resistance. The charging current will produce a quadrature voltage. Typical winding resistance is a few ohms.

CORE LOSS RESISTANCE

1000 turn windings on Supermaloy cores, which exhibit a premeability of 100, 000, produce a core loss resistance of a few megohms at 1kc. This resistance reduces to a few hundred thousand ohms at 100 cps.

3.2 LOADING EFFECTS

CAPACITIVE LOADING

The tight winding required for optimum flux linkage produces a high inter-winding capacitance. This capacitance is so high that its impedance is quite comparable to, and is often greater than, the impedance of the charging inductance. Much of the current in the upper half of the winding flows in through the series leakage impedance and out through the leakage capacitance. In the lower half of the winding the reverse is true, the current flows in through the leakage capacitance and out through the leakage inducatance. Current through the leakage inductance produces a slight positive linearity deviation at high settings and a slight negative linearity deviation at low settings with a very low deviation at mid-scale, (see Figure 3.2a).

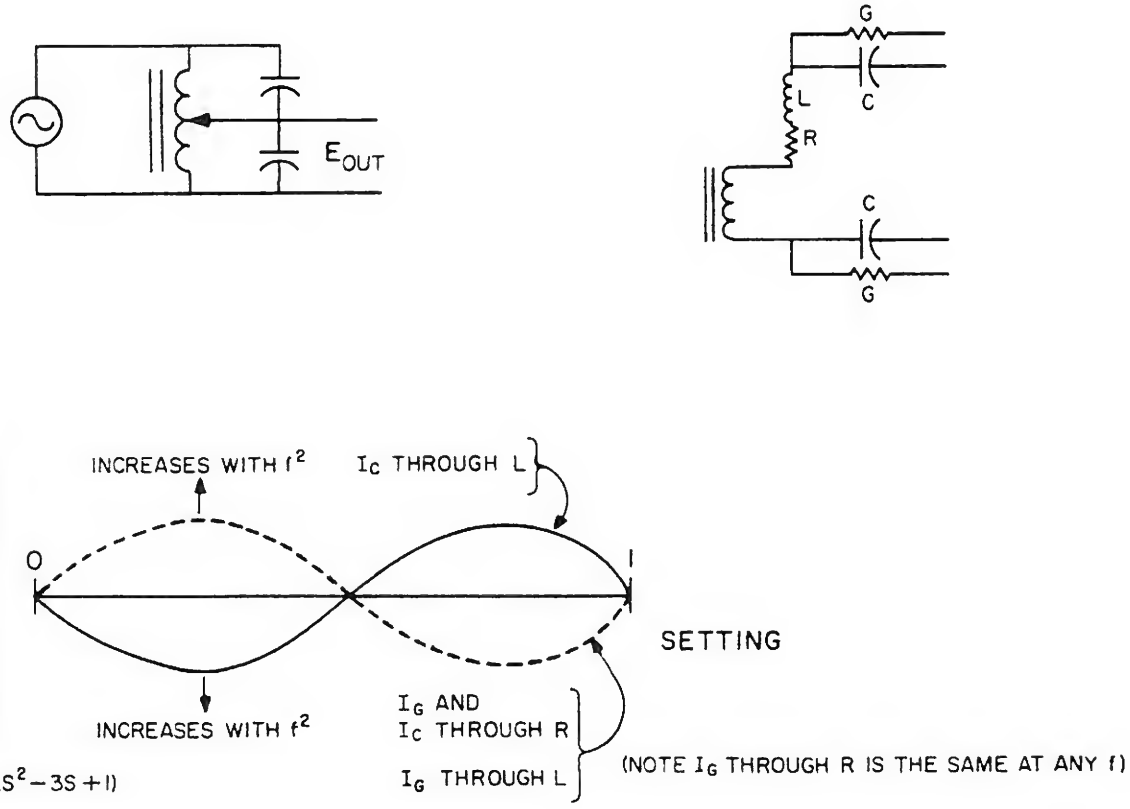


FIG. 3.2a

The capacitive current through the resistance of the windings produces a linearity deviation in the opposite direction so it is possible to build a transformer which will operate with these two effects almost balanced. Transformers of this design have been made with accuracies in the order of 0.02 ppm. The linearity deviation due to capacitive loading goes up with the square of the frequency. The phase shift due to capacitive loading goes up linearly with frequency.

The current passing through the leakage conductance of the insulation between windings causes a linearity deviation and phase shift when it passes through the leakage impedance. These changes are of the same polarity as those caused by the capacitive current through the leakage resistance. If the leakage conductance is fairly constant with frequency, the contribution of the leakage resistance will not change with frequency but the contribution of the leakage inductance will vary with frequency. Linearity deviation increases with the square of frequency and phase difference increases directly with frequency.

OUTPUT LOADING

A slightly different equivalent circuit can be considered for determining the effects of output loading on a transformer divider. The leakage impedance and copper resistance, which can be considered to be in series with the output lead of the transformer, can be measured at the output terminals by shorting the input terminals. The voltage drop produced by load current relative to the input voltage across this measured impedance will give the linearity deviation to be expected.

ACCURACY

The sum of all of these effects combined with other much smaller second order effects determine the accuracy at any setting, frequency, load and voltage combination.

SECTION IV

MAINTENANCE

4.1 ACCESSING COMPONENTS

Prepare a soft, clean place to set the instrument. Be sure that no projections or pointed objects will be underneath it and that there are no metal filings in the area.

Remove the instrument from the rack and place it face down on the prepared surface. Loosen the screws on the back of the unit and carefully slide the dust cover off.

4.2 PERIODIC MAINTENANCE

The following procedures should be performed approximately once a year to insure maximum accuracy and reliability from the Model DT 72A Decade Transformer. If problems can be isolated, the defective part should be returned to the factory for repair or replacement. If the need for major repairs is apparent, it is recommended that the unit be sent to the factory for service. If you are unable to release the unit, the service department will be happy to furnish the necessary information and replacement parts. Unauthorized repairs, however, will invalidate the instrument warranty.

4.2.1 Visual Inspection

Inspect the outside of the unit for dial orientation and damage to binding posts and binding post caps. Check for dirt around binding post insulators.

Inspect the interior for loose or broken connections, damaged or dirty switch contacts, heat-damaged resistors and resistors touching each other or the grounded switch structure.

4.2.2 Cleaning and Lubrication

Clean the front panel with a soft, dry, lint-free cloth, being particularly careful to remove all dirt from around binding post insulators.

The only internal components that may require maintenance are the rotary switches. Carefully lubricated at the time of manufacture and protected by the instrument case, they should rarely, if ever, require maintenance. It is recommended that they be cleaned and lubricated *only* if they are not making good electrical contact. In such a case, proceed as follows:

1. Place instrument horizontally on bench, with a sheet of white paper under switch to be cleaned. Spray switch with Freon TF degreaser in aerosol can (Miller Stephenson Co. or equivalent) until no more dirt appears on paper. Drying is not necessary.

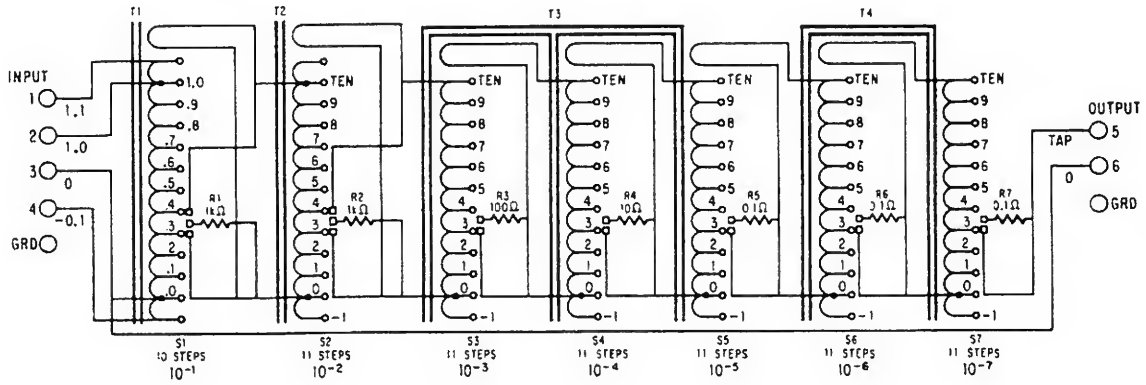
2. Lubricate with a low-conductivity oil (Viscosity Oil Co., No. 7069 or equivalent). Apply one drop to each rotor tab and one drop to the rotor ring contact, using a hypodermic needle. With a small brush, apply a dab of petroleum jelly to each switch bearing and detent mechanism. DO NOT OVERLUBRICATE.

   A lubrication kit is available from ESI which contains Freon degreaser and low-conductivity oil. The part number for this kit is 1343.

4.3 REPLACING THE DUST COVER

Be sure that the interior of the unit and dust cover are completely clear of all foreign material. Slip the dust cover over the unit and replace the screws.

4.4 SCHEMATIC DIAGRAM



SECTION V

PARTS LIST

The following parts list is in alpha-numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers (see list of manufacturers below).

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering, include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

01121 ALLEN-BRADLEY COMPANY, Milwaukee, Wisconsin
11837 ELECTRO SCIENTIFIC INDUSTRIES, INC., Portland, Oregon

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
A1	Transformer Box Assembly	703-7229
T1, T2	Transformer	*
T3	Transformer	*
T4	Transformer	*
R1, R2	Resistor, 1 kΩ, 1 W, ±10%	304-1969
R3	Resistor, 100 Ω, 1/2 W, ±10%	304-1977
R4	Resistor, 10 Ω, 1/2 W, ±10%	304-2039
R5-R7	Resistor, 0.1 Ω	304-7204
S1	Switch, Rotary	201-7212
S2	Switch, Rotary	201-7213
S3-S7	Switch, Rotary	201-7214
	Insulator, Binding Post	413-8823
	Window, Thick	121-8672
	Window, Thin	121-7242
	Binding Post	112-1474
	Binding Post	112-1475
	Cap, Binding Post, Metal	112-1172
	Cap, Binding Post, Grey	112-1476
	Knob, Large Bar, Grey	110-1458
	Dial, 3rd, 5th and 7th	101-7881
	Dial, 1st	101-7819
	Dial, 2nd, 4th and 6th	101-7810

*Part of Assembly A1, not available as a separate item.

WARRANTY OF TRACEABILITY

The reference standards of measurement of Electro Scientific Industries, Inc., are compared with the U.S. National Standards through frequent tests by the U.S. National Bureau of Standards. The ESI working standards and testing apparatus used are calibrated against the reference standards in a rigorously maintained program of measurement control.

The manufacture and final calibration of all ESI instruments are controlled by the use of ESI reference and working standards and testing apparatus in accordance with established procedures and with documented results. (Reference MIL-STD 45662)

Final calibration of this instrument was performed with reference to the mean values of the ESI reference standards or to ratio devices that were verified at the time and place of use.

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